

Study of Soils in the Drumlin Belt of North Central Ireland

By *M. Walsh*^{*)} and *F. de Coninck*^{**)†}

Introduction

The drumlin belt of north-central Ireland occupies an area of over 1 million hectares. Enclaves - 5 to 10 hectares - of undulating topography, locally known as "rockland", and more extensive lacustrine and alluvial flats occur between the drumlins. Proximity of bedrock to the surface and frequent rock outcrop clearly distinguish the "rockland" from the drumlins. The dominant slopes on the former range from 2° to 5° and, on the latter from 7° to 15°. The altitude varies between 50 and 70 m O.D.

Carboniferous limestones, shales and sandstones, and Ordovician shales and sandstones form the main bedrocks. These are largely mantled by glacial till which is moulded into classically shaped drumlins with a "stoss" end facing the source of ice movement. The geological composition of the till in the drumlins and in the rockland is essentially that of the underlying bedrock.

The climate is cool temperate oceanic - Cfb (*Köppen*), AC₂rb₂ (*Thorntwaite*) - with a mean annual temperature of 8° to 9°C. Mean annual precipitation varies from 1,500 mm in the west to 890 mm in the east and is fairly well distributed throughout the year.

Problem

Fine-textured aquepts occur on many of the till drumlins regardless of changes in parent material or slopes. Soils on associated rockland differ little in texture from drumlin aquepts but they generally have a better natural drainage and a wider variety of profile development. Aquepts, aqualfs, udalfs, ochrepts and orthods occur in varying complexes on rockland.

Quinn and Ryan (1962) and *Mulqueen and Burke* (1967) have highlighted the difficult problems of drainage and of soil management for agricultural purposes on till drumlin aquepts. The rockland soils are generally more amenable to agriculture.

This study is an attempt to explain the genesis of and the difference between some drumlin aquepts and associated rockland soils.

Soils and Methods

Morphology

Five soil profiles, three on till drumlins and two on associated rockland, were described and sampled. The parent materials of the drumlin soils consist of till, derived mainly from siliceous

^{*)} Soil Survey, An Foras Taluntais, Johnstown Castle, Wexford, Ireland

^{**)†} Geological Institute, State University Ghent, Rozier 44, Ghent, Belgium

limestone (soil 1), calcareous shale (soil 2) and interbedded shales and sandstones (soil 3). The parent materials of the rockland soils, 4 and 5, are similar to those of soils 2 and 3. A rockland soil on siliceous limestone is not included because of its similarity with that on calcareous shale.

For morphological details, the following two descriptions are given. Both are on calcareous shale, profile 2 is the drumlin soil, profile 4 the rockland soil.

The drumlin soil is generally wet throughout the year and so is described in the wet state. The rockland soil, however, is generally moist and is described in this state.

Profile 2 – Alfic Haplaquept on Drumlin

0–5 cm: A11; Clay; grey yellowish brown (10 YR 4/3)*; weak coarse granular; friable; abundant fine roots; clear smooth boundary to:

10–23 cm: A2g; Clay; yellow brownish grey (10 YR 5/2) with common light brown (7.5 YR 5/6) mottles along root channels; few micropores; weak coarse prismatic breaking to medium angular blocky; slightly sticky, slightly plastic; common roots; clear wavy boundary to:

10–23 cm: A2g; Clay; yellow grey (10 YR 5/2) with common light brown (7.5 YR 5/6) mottles along root channels; few micropores; weak coarse prismatic breaking to medium angular blocky; slightly sticky, slightly plastic; common roots; clear wavy boundary to:

23–42 cm: B1g; Clay; yellowish brown (10 YR 5/6) with many coarse prominent grey (2.5 Y 6/0) mottles; massive; sticky, plastic; common roots; gradual smooth boundary to:

42–55 cm: B2tg; Clay; grey (2.5 Y 5/0) with many prominent coarse yellowish brown (10 YR 5/6) mottles; massive; sticky, plastic; few roots; gradual smooth boundary to:

55–75 cm: C1g; Clay; yellowish brown (10 YR 5/5 – 5/6) with many prominent yellow brownish grey (10 YR 5/0) mottles; massive; sticky, plastic; few large decaying roots; very gradual smooth boundary to:

75–100 cm: C2g; Similar to Clg but with greenish grey colours in matrix.

Profile 4: Typic Haplaquept on Rockland

0–5 cm: A11; Clay; yellow brownish grey (10 YR 4/2); moderate medium granular and fine subangular blocky; friable; abundant roots; clear smooth boundary to:

5–13 cm: A12; Clay; yellow brownish grey (10 YR 5/1) with common distinct fine light brown (7.5 YR 5/6) mottles; moderate medium subangular blocky; friable; frequent roots; clear smooth boundary to:

13–25 cm: A2; Clay; yellow brownish grey (10 YR 6/1) with few distinct fine light brown (7.5 YR 5/6) mottles along root channels; moderate medium and coarse subangular blocky; friable; common roots; clear smooth boundary to:

25–40/45 cm: B2g; Clay; yellow brownish grey (10 YR 6/1) with common distinct fine light brown (10 YR 5/6) mottles; moderate coarse prismatic; slightly plastic, slightly sticky; grey (2.5 YR 6/0) clay cutans on the major ped faces; many fine pores in interiors of peds; common roots along ped faces; clear wavy boundary to:

40/45 cm: R; Weathering calcareous shale.

The three drumlin soils have a rather similar horizonation and morphology and are classified as alfic haplaquepts. The difference between Bg and Cg is based on the difference in structure (weak coarse prismatic in the Bg merging gradually with massive in the Cg).

Soils 4 and 5 on the rockland are classified as a lithic haplaquept and a typic haplorthod respectively.

Morphological differences between drumlin and rockland soils are confined to differences in structure and consistency. The former have a very weak crumb structure in the surface horizon,

*) Soil colours refer to field-wet *Munsell* colour notation

are weak coarse prismatic in the Bg and massive in the Cg with a sticky and plastic consistency throughout. The latter soils are moderately strong granular in the surface horizon and moderate subangular blocky in the B(g) and have a friable consistency throughout.

None of the soils possess a water-table. The colours of the drumlin soils indicate active oxidation and reduction processes while those of the rockland soils are more homogeneous.

The organic matter content is generally higher and plant remains are less humified in the drumlin soils than in the rockland soils.

Despite a textural increase in the B horizon, continuous clay skins were not observed in the field. Illuviation of fine soil material was, however, apparent along prism faces.

Analytical methods

Analytical data include particle size distribution, pH, organic carbon and total elemental analyses determined by conventional methods. Fe and Al extracted by dithionite - citrate treatment on the $< 2 \mu$ fraction (Mehra and Jackson, 1960, De Conick et al., 1968) were determined. X-Ray diffractograms were prepared from the silt fraction and the < 2 micron fraction before dithionite-citrate treatment. Following treatment, the clay samples were again X-rayed in the following ways: (i) Mg saturated, (ii) Mg saturated, solvated with glycol, (iii) K saturated, (iv) during gradual heating of both Mg and K saturated to 550°C . Thin sections were prepared from oriented and undisturbed soil samples for micromorphological examination.

Results and Discussion

Micromorphology *)

Micromorphology shows clear differences between the drumlin and the rockland soils. The s-matrix of the drumlin soils is dense with a porphyroskeletal related distribution. That of soil 4 is somewhat denser and has more regularly shaped voids suggesting a more orderly packing of the material. Soil 5 due to the presence of many fecal pellets, has loosely packed s-matrix with agglomeroplastic related distribution. The general colour of the s-matrix is darker than that of the corresponding drumlin soil due a more homogeneous distribution of iron within the horizons.

The plasmic fabric of the A horizons of the drumlin soils varies from silasepic to weak skel-insepic. The A horizon of soil 4 has a weak skel-masepic fabric. The lower horizons of the drumlin soils have strongly developed skel-vo-masepic as well as some enclaves of clinobimasepic and omniseptic fabric. Many separations consist of original argillans being reincorporated into the s-matrix. The plasma separations are best preserved where coated with sesquioxidic material but are in the course of disruption where bleached and free of sesquioxides. The lower horizons of soil 4 are also skel-vo-masepic but the plasma separations are more strongly oriented and apparently more stable than in the drumlin soils.

Aseptic plasmic fabric characterises the entire profile of soil 5. This contrasts strikingly with the corresponding drumlin soil which displays the best developed skel-vo-masepic fabric.

Voids with or without interconnections are more plentiful in the rockland than in the drumlin soils. The latter have a greater proportion of planar and channel voids to vughs

*) the terminology employed is that of Brewer, 1964

than the former. This indicates a greater amount of stress due to swelling and shrinking in the latter than in the former soils.

The voids in the drumlin soils are mainly irregular meta- and orthochannels with some meta- and ortho-skew planes and meta- and orthovughs. Some vesicles occur in the lower horizons of soil 3. The rockland soils contain mainly orthovughs and -channels with very few planar voids. Metavoids are also present in soil 4.

Many cutans of plasmic and sesquioxidic material occur in the lower horizons of the drumlin soils. They are present to a lesser extent in soil 4 and almost completely absent from soil 5 apart from a few neo-ferrans in the surface horizon. The argillans and ferriargillans of the drumlin soils often have a disrupted structure. They are much larger than the more tightly packed illuviation ferriargillans of soil 4. The latter also have a stronger and more continuous orientation. The drumlin (ferri)argillans appear to result from illuviation and localized mass movement of plasmic material. The most pronounced plasma concentrations are present in soil 3 which has the highest sand and lowest clay contents of all the soils. Neo-ferrans and quasi-ferrans, many originating from plant remains, are most common in the drumlin soils. Many quasi-ferrans in the lower horizons of the drumlin soils occur within void argillans forming compound pedological features. Ferrans occur rarely in the rockland soils.

Glaebules, consisting mainly of sesquioxidic nodules and concretions, are common in the drumlin soils. They originate mainly from plant remains in the surface horizons and from plasma separations and concentrations in the lower horizons. The nodules are generally large, irregularly shaped, diffuse and undifferentiated while the concretions,

Table 1
Mechanical (pipette) and Chemical Analyses

| Horizon | % C. Sand 2000-200 μ | F. Sand 200-50 μ | Silt 50-2 μ | Clay 2 μ | C (%) | pH | Free Al_2O_3 (%) |
|------------------|-----------------------------|-------------------------|--------------------|-----------------|----------|-----|-------------------------------------|
| <i>Profile 2</i> | | | | | | | |
| A ₁₁ | 7 | 8 | 43 | 42 | 10.3 | 6.1 | 1.09 |
| A ₁₂ | 6 | 9 | 41 | 44 | 6.2 | 6.2 | 0.56 |
| A ₂ | 9 | 10 | 38 | 43 | 2.1 | 6.4 | 1.29 |
| B _{1g} | 5 | 6 | 40 | 49 | 1.0 | 7.1 | 1.04 |
| B _{2g} | 6 | 6 | 35 | 53 | 0.7 | 7.2 | 1.72 |
| C _{1g} | 7 | 7 | 36 | 50 | 0.7 | 7.4 | 1.92 |
| C _{2g} | 6 | 6 | 42 | 46 | 0.9 | 7.5 | 1.39 |
| <i>Profile 4</i> | | | | | | | |
| A ₁₁ | 4 | 5 | 41 | 50 | 8.8 | 5.1 | 0.61 |
| A ₁₂ | 6 | 6 | 42 | 46 | 4.3 | 5.0 | 1.04 |
| A ₂ | 5 | 5 | 44 | 46 | 2.6 | 5.1 | 0.56 |
| Bg/R | 3 | 4 | 37 | 56 | 1.2 | 5.3 | 0.73 |

also diffuse, consist mainly of a single outer band. Glaebules are also common in soil 4 but are rarely seen originating from plant remains even in the surface horizon. Here the glaebules consist mainly of discrete, undifferentiated spherical nodules. These nodules are smaller, more clearly expressed and apparently more stable than in the drumlin soils. Glaebules are almost totally absent from soil 5.

Fecal pellets are present in the surface horizons of all the soils. In the drumlin soils they are irregularly shaped and seem to be easily disrupted. The pellets of the rockland soils have smoother outlines and a more intensely mixed matrix giving a more stable appearance. Fecal pellets, often enclosed in voids, occur throughout soil 5. Thus, a more effective biological activity is present in the rockland than in the drumlin soils.

Mineralogy

The silt fraction (50 μ –20 μ) is composed mainly of quartz, chlorites, micas and felspars. Soil 3 has the lowest amount of quartz. The B horizons generally contain more weatherable minerals than the A horizons. There is little difference in composition between drumlin and rockland soils which are derived from similar parent materials.

The clay mineralogical analyses of the < 2 μ fractions show a rather uniform composition: the most important components are illite, quartz, kaolinite and 14 \AA minerals which are mostly chlorites and intergrades chlorite-vermiculite or illite-vermiculite. Swelling minerals

Table 2
Free iron content (% Fe_2O_3) in total soil (< 2 mm) and clay (< 2 μm)

| Profile and Horizon | soil | clay | Profile and Horizon | soil | clay |
|---------------------|------|------|---------------------|------|-------|
| 1 Drumlin | | | 3 Drumlin | | |
| O_1 | 0.3 | 1.72 | A_{11} | 2.0 | 3.28 |
| A_1 | 0.6 | 0.63 | A_{12} | 3.6 | 6.58 |
| A_{2g} | 0.6 | 0.95 | B_{1g} | 2.9 | 6.53 |
| B_{1g} | 3.8 | 7.92 | B_{2g} | 3.1 | 8.40 |
| B_{2g} | 3.6 | 7.01 | C_{1g} | – | 8.15 |
| C_g | 3.4 | 5.86 | 4 Rockland | | |
| 2 Drumlin | | | A_{11} | 1.9 | 1.66 |
| A_{11} | 0.9 | 1.81 | A_{12} | 2.5 | 2.65 |
| A_{12} | 1.9 | 1.23 | A_2 | 2.8 | 2.22 |
| A_2 | 2.3 | 2.79 | $\text{B}_{g/R}$ | 2.8 | 2.99 |
| B_{1g} | 3.8 | 6.19 | 5 Rockland | | |
| B_{2g} | 3.5 | 5.98 | A_{11} | 3.7 | 8.62 |
| C_{1g} | 3.0 | 6.19 | A_{12} | 4.0 | 10.40 |
| C_{2g} | 2.7 | 5.17 | B_{2ir} | 3.9 | 15.61 |
| | | | C | 2.4 | 12.74 |

are present only in a few horizons. The B horizons of the 3 drumlin soils have lepidocrocite, but this mineral is absent in the rockland soil.

Interesting evolutions in the clay mineral composition are present within some profiles (weathering of chlorite, and chloritisation of both vermiculite and illite) but these do not seem to be in relation with the special character of the drumlin soils and the difference in behaviour with the rockland soils. Although montmorillonitic minerals are mostly absent, micromorphological studies point to the presence of strong forces causing stress and mass movement in the soil. This indicates that swelling minerals are not necessary to cause strong swelling and shrinking in the soil.

Another interesting feature is the presence of lepidocrocite in the drumlin soils and its absence in the other soils. Although the free iron content is about the same in both, only the drumlins have this iron mineral, which is typical for poorly drained soils.

Some profiles show a slight increase of quartz in the A horizon, but this alone is not responsible for the poor structure as previously thought. The amount of quartz is not higher in the drumlin than in the rockland soils, and is comparable to many other soils showing good structure and good drainage.

Chemical Analyses

All the drumlin profiles show an increase in clay content in the B2g. The pH is normally lower in the rockland than in the drumlin soils, probably due to the better natural drainage of the former (Tab. 1).

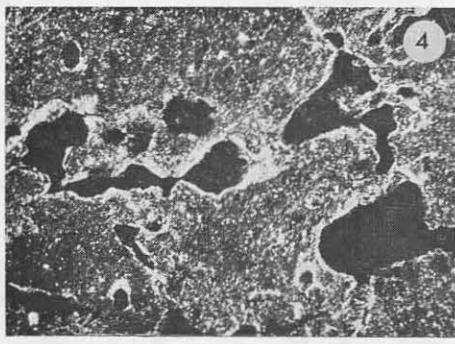
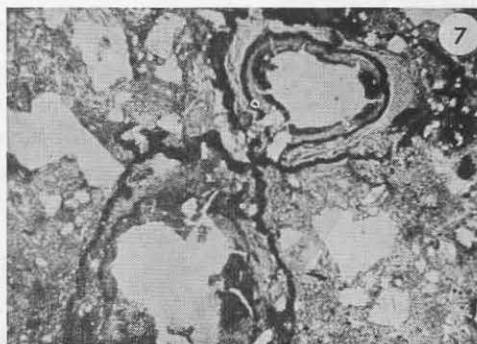
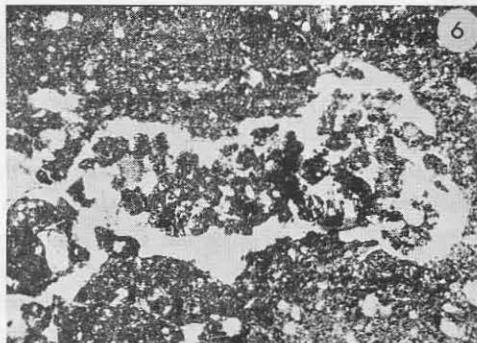
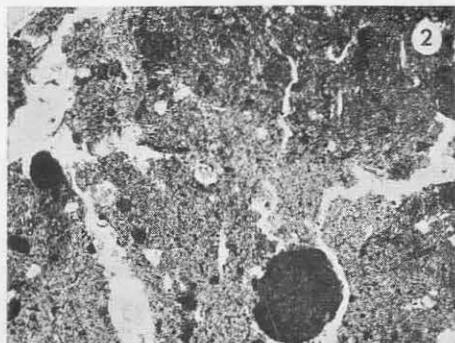
The free iron content in the total soil and in the clay fraction shows some striking differences (Tab. 2). In the surface horizons of the drumlin soils the free iron content in total soil and clay is similar. This may mean that the distribution is equal in the clay and total soil or that it is distributed proportionately between the two fractions. The same feature occurs in the whole profile of soil 4 (the rockland).

However, the free iron content of the clay fraction in the B horizons of the drumlin soils is generally double that in the total soil. This indicates that most of the free iron is present in the clay fraction or that it is easily dispersible or finely divided on the clay particles.

This feature is consistent with the micromorphological observations. These show very many small but strong iron accumulations in the A horizons of the drumlin soils and throughout profile 4, while in the B horizons the iron oxides are regularly distributed throughout the whole matrix in the form of weak diffuse accumulations.

It is possible that in the drumlin soils, due to the strong stress, clear nodules or concretions never have time to form as the incipient iron accumulations are continually being disrupted and displaced. In profile 4, however, strongly pronounced iron accumulations occur in the form of nodules or as part of ferriargillans associated with meta-voids. These special forms of iron accumulation seem to form a frame, helping to maintain the rigidity of the soil mass.

The total elemental analyses did not show significant differences in the various horizons of the profiles and it was not possible to draw clear conclusions from them.



- 1 Iron accumulation beginning on plant fragment; A₁₂ of drumlin aquept: $\times 30$, plain light.
- 2 Discrete sesquioxidic nodules, organic remains well intermixed in s-matrix; A₁₁ rockland aquept: $\times 30$, plain light.
- 3 Argillans and ferriargillans in B_{2g} of drumlin aquept: $\times 30$, crossed nicols.
- 4 Void ferriargillans in B_g of rockland aquept: $\times 30$, crossed nicols.
- 5 Bleached plasma separations (mascpic) and large sesquioxidic nodules; B_{1g} of drumlin aquept: $\times 30$, crossed nicols.
- 6 Fecal pellets in vugh in B_{2ir} of rockland orthod: $\times 30$, plain light.
- 7 Compound pedological feature-void ferriargillans with quasi-ferrans - B_{2g} of drumlin aquept: $\times 80$, plain light.

Conclusion

The drumlin soils behave differently under agriculture from the rockland soils.

There is no consistent difference in weathering and composition of the clays between soils on similar parent materials. There appears to be no relationship between the mineralogical and physico-chemical composition and the different behaviour of the soils. The amount of quartz in the clay fraction is not, as originally held, responsible for the poor structure of the drumlin soil (*Mulqueen and Burke, 1967*).

Soil structure is weak and ill-defined in the drumlin soils whereas it is moderately strong and more clearly defined in the rockland soils. Consistency in the natural state is generally sticky and plastic throughout the year in the former but generally friable in the latter soils.

Micromorphologically the soils differ most in the occurrence and nature of voids, cutans, glaebules and fecal pellets. The drumlins have a lower porosity with fewer and more irregularly shaped voids, but a greater proportion of planar voids, the latter being an expression of greater stress in the soil.

The weaker orientation of the cutans in the drumlins suggest a more intense, localised disturbance of the plasmic material.

The distribution of different free-iron features in the profiles – large diffuse accumulations in the drumlins, and small, discrete nodules and ferriargillans in rockland – again points to strong and continuous rearrangement of the soil mass due to internal stress phenomena in the former. In the latter, they form stable aggregates which seem to lend rigidity to the soil.

The nature of the pores and low porosity in the drumlin soils may result partly from pressure exerted by the moving ice-mass during drumlin formation.

The rockland soils are developed on morainic material which was probably deposited when the ice-mass was melting and not subjected to great pressures as above.

The fecal pellets indicate a more active and deeper biological activity in the rockland than in the drumlin soils. The rockland soil 5, derived from Ordovician material, with its abundant fecal pellets and almost complete absence of plasma aggregates and glaebules, offers a greater contrast with its corresponding drumlin soil than that of the soils derived from Carboniferous materials.

In our opinion the evolution of these soils must have originated from differences in original packing and proximity of the bedrock. These factors have caused a difference in natural drainage. We could clearly establish that in the drumlins existing pores are closed soon after they had been formed, while in the rockland many of the pores are stabilized by ferriargillans. Since the mineralogical composition is identical in both cases we must conclude that the poorer drainage causes a higher stress within the soil mass, closing the pores before they can be stabilized and maintain themselves.

Acknowledgement

The authors express their thanks to the field and laboratory staff of the National Soil Survey, An Foras Taluntais, Johnstown Castle, Wexford (Ireland), and to the staff of the soil laboratories of the Geologisch Instituut, Rijksuniversiteit, Ghent (Belgium).

References

Brewer, R., 1964 - Fabric and Mineral Analysis of Soils: John Wiley & Sons, Inc., N.Y.

De Coninck, Fr. Herbillon, A. J., Travernier, R. and Fripiat, J. J., 1968 - 9th Int. Congr. Soil Sci. Adelaide. IV, 353-365.

Mehra, O. P., Jackson, M. L., 1960 - Clays Clay Miner. 5, 317-327.

Mulqueen, J., Burke, W., 1967 - Research on Drumlin Soils: An Foras Taluntais, Dublin.

Quinn, E., Ryan, P., 1962 - Transact. Joint Meeting Comm. IV and V. Int. Soc. Soil Sci. Palmerston North 639-646.

Summary

Five soils representing some of the more important variations in the drumlin belt of north-central Ireland are studied. Three of the soils, aquepts, occur on drumlins and two, an aquept and an orthod, occur on associated rockland. Both groups of soils occur on corresponding parent materials but have contrasting morphological characteristics. Differences in chemical, physico-chemical, mineralogical and micromorphological properties are discussed. A tentative explanation for the varying characteristics and behaviour of the two groups of soils is given.

The main differences between the soil are believed to be originally due to their mode of deposition.

Résumé

Cinq sols représentant quelques-unes des plus importantes variations dans le Drumlin Belt (Nord de l'Irlande centrale) ont été examinés.

Trois des sols, Aquepts, se trouvent sur Drumlins, et deux, un Aquept et un Orthod, sont sur le « rockland » associé. On trouve les deux groupes de sols sur des matériaux parentaux correspondants, mais ils ont des caractéristiques morphologiques contrastés. Les différences en composition chimique, physico-chimique, minéralogique et micro-morphologique sont discutées. Un essai est fait pour une explication des deux groupes de sols. Les différences principales entre les sols proviennent probablement de leur mode de dépôt.

Zusammenfassung

Fünf Böden als einige der wichtigeren Vertreter im Drumlin Belt (Nord-Mittelirland) werden untersucht. Drei der Böden, Aquepts, kommen auf Drumlins vor, und zwei, einen Aquept und einen Orthod, findet man im angrenzenden Felsengebiet. Beide Bodengruppen trifft man auf entsprechenden Ausgangsgesteinen, aber sie haben kontrastierende morphologische Merkmale. Unterschiede in chemischen, physiko-chemischen, mineralogischen und mikromorphologischen Eigenschaften werden diskutiert. Ein Erklärungsversuch für die unterschiedlichen Merkmale und das Verhalten der beiden Bodengruppen wird gegeben. Die Hauptunterschiede zwischen den Böden sind wahrscheinlich ursprünglich durch die Ablagerungen bedingt.